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Anatomy is an unusual subject because the material we use is human. This gives, at one and the same time, a fascination and a repugnance, simply because the material is human.

> 'The study of anatomy by dissection requires in its practitioners the effective suspension or suppression of many normal physical and emotional responses to the willful mutilation of the body of another human being' - Richardson

In other words, in normal society, outside the medical school we would probably be locked up for dissection, and its not very nice anyway, is it? The name given to the ability to suppress physical and emotional responses is 'clinical detachment'. Clinical detachment is the way in which we deal, as anatomists, with the repugnant, the distasteful, and what, if we did it to a living human being, would be criminal. It is acquired slowly, bit by bit, and to different extents. William Harvey, discoverer of circulation of the blood, dissected both his father and his sister. Few of us would wish to be so clinically detached.

If we did it to a living human being is the key phrase. The cadaver is not a living human being but neither is it a pound of offal.. Perhaps we should examine our attitude to our own, and other peoples' bodies.

Man has always been fascinated by the interior of his body. The first written documents to survive are clay tablets from around 4000BC in Nineveh. The cuneiform script impressed upon these tablets can be translated, and tells us many things. Some tablets are inventories for warehouses, some are the equivalent of laundry lists, and some tell us about the insides of men and animals opened in a form of fortune telling - trying to predict the future.

The next landmark was anatomical detail set down by Galen in the second century AD. This was meagre, distorted and bore little relationship to the dissected body.

In the Renaissance a change of attitude occurred: in Italy this took the form of patronage and the setting up of schools of anatomy, notably at Padua, and the work of the first two great anatomists, Leonardo da Vinci and Versalius. Da Vinci's work was hidden until the late eighteenth century but Versalius De Humani Corpus Fabrica, published in 1543 was the first anatomy textbook as we know it, drawn from life (or death), accurate and painstaking.

England, as usual in things European, lagged behind, but Scotland granted royal patronage to the Edinburgh College of Surgeons and Barbers in 1506. England followed suit in 1540. (Surgeons thus have a long connection with barbers: this is because medical men denied them professional status, and leads to the inverted snobbery of the consultant surgeon whose title is still MR . The low status of the surgeon, which dated from the Council of Tours edict in 1163 whereby the church abhorred the spilling of blood. Ecclesiastics who were also medics were thus discouraged from surgery, although they continued to practice medicine, and subcontracted surgical procedures to others, often barbers, who performed blood letting, tooth drawing and later midwifery.)

It is at this point that things get complicated and that Anatomy starts to get a bad name. Part of the patronage given by James IV of Scotland was the bodies of certain executed criminals for dissection. In England Henry VIII granted the annual right to the bodies of four hanged felons. Charles II later increased this to six . Now bodies had to come from somewhere, but the conjoining of anatomy and hanging offences was very bad news, and the basis of an association which lasted until the first Anatomy act in 1832. Dissection was now a recognised punishment, a fate worse than death to be added to hanging for the worst offenders.

The dissections performed on hanged felons were public: indeed part of the punishment was the delivery from hangman to surgeons at the gallows following public execution, and later public exhibition of the open body itself. The punishment replaced the earlier hanging drawing and quartering, in which the four quarters were exhibited on spikes in various parts of the city, and differed only in that it was performed by medical men, and, incidentally that anatomical knowledge was obtained. This state of affairs was accepted by surgeons because it was, oddly, good for their image to achieve royal patronage and to be linked with the law. In France, incidentally surgeons acquired respectability by the back door. In 1687 surgeons performed a successful operation for anal fistula on Louis XIV. It was successful, probably because they practised for a year on lesser mortals with the same complaint. In 1752 an act was passed allowing dissection of all murderers as an alternative to hanging in chains. This was a grisly fate, the tarred body being suspended in a cage until it fell to pieces. The object of this and dissection was to deny a grave. After the act the number of available bodies increased, and the act itself was pro anatomy in that the execution had to follow smartly upon conviction, and the body conveyed immediately to the surgeons. Dissection was described as 'a further terror and peculiar Mark of Infamy' and 'in no case whatsoever shall the body of any murderer be suffered to be buried'. The rescue, or attempted rescue of the corpse was punishable by transportation for seven years.

The act benefited anatomists immediately. In 1775 the royal college of surgeons acquired eight bodies at once before rigor mortis had set in: one was 'put in an attitude and allowed to stiffen' by William Hunter, Professor of Anatomy, flayed and a mould prepared. A cast from this is still on view at the Royal Society of Arts in London.

Hunter was a key figure in Anatomy. He ran his own private anatomy school in Great Windmill St in London where he thought in the 'Parisian manner', each student having access to an individual corpse. He also set up a museum of human and comparative anatomy. The Company of Surgeons was 'intellectually stagnant' at this time, had no hall and was more interested as a City livery company in giving public dinners than offering public dissection. Despite this, in the period between 1701-1744, 24 lecturers in anatomy are known to have been active in London alone. The private schools had no legal status and no legal source of material. The question was, where did Hunter, his brother and the other anatomists setting up private schools get their cadavers - certainly not from official sources. The suspicion, probably justified, was that people were being paid to obtain corpses. The corpse was now a commodity: it had cash value and could be bought and sold. Harvey's solution of keeping it in the family did not become popular: most anatomists bought from the gallows or the grave.

Agents representing surgeons would bargain with condemned prisoners not under sentence of dissection (remember this only happened for murder: hanging was in vogue for stealing a sheep or even a loaf) : occasionally prisoners struck a bargain to pay expenses, to provide for a family or to buy the customary decent apparel for the hanging. Supply was unreliable, however: riots at public hangings became common, partly because of the paltry nature of hanging events, partly from superstition. The body was often reclaimed by relatives and the unpopular anatomists stoned, defeated and out of pocket. Competition was often so fierce that a rival anatomy school carried off the body. Dissection was unpopular and other medical uses were to be found for a recently hung body - the cure of scofula, goitre, wens, ulcers, bleeding tumours, cancers and withered limbs for example. To prevent riots and disorder the Sheriff of London took all bodies of hanged men, except those sentenced to dissection, into his own custody and handed them to the relatives for burial.

However in 1826 592 bodies were dissected by students at London anatomy schools. Most of these must have come from grave robbers. The earliest grave robbers seem to have been the surgeons themselves. In 1721 a clause was inserted into apprentices indentures issued by the Edinburgh college of surgeons forbidding trainee surgeons from becoming involved in exhumation. Later, students accompanied professional body snatchers as observers. In Scotland it was possible to pay fees in corpses rather than in cash. By the 1780s the work was left to the professionals -Ressurectionists or Sack' em up men. A professional gang of 15 body snatchers was rounded up in Lambeth in 1795.

They worked, winter only, serving 'eight surgeons of repute' from 30 burial grounds. Corpses cost two guineas and a crown -£2.35 and children six shillings for the first foot and nine pence for each extra inch. By 1820 the cost was up to 20 guineas for an unremarkable corpse for dissection. Freaks cost a lot more. O'Brien, the Irish giant, well over seven feet tall, who died in 1783 was bought by John Hunter for £500, despite his wish to be buried at sea to avoid such a fate. He now stands in the entrance of the Royal College of Surgeons in London.

Oddly body snatching was not an offence. The body was not regarded as property, and, once dead, could not be owned or stolen. Occasionally a body snatcher would be whipped, on unclear legal grounds. Only if property - such as a shroud was removed was the robber a thief.

The grave robbers job was easier if the graves of the poor were robbed. Pit burials, or mass graves were common, and often a large square pit up to 20 feet deep would be excavated, filled with coffins gradually over a period of weeks then closed. Stealing bodies from such graves cannot have been difficult. The wealthy, of course could buy a metal coffin (1781), Bribgeman's patent cast iron coffin (1818) or use a mortsafe - a kind of cage of iron bars surrounding a tomb. They could also, and did, employ guards, even armed guards to ensure their eternal rest. The poor, acting in concert to reduce the cost often had a parish mortsafe or 'jankers' where bodies were kept until too high for the anatomist to use.

The demise of the body snatcher is perhaps one of the first cases of consumerism. Since the law was unable or unwilling to help, because of the lack of a clear offence, it was left to the public to intervene. Thus in 1828 two medical students caught attempting to snatch a body were committed to gaol at their own request as they were threatened by a large crowd. The following afternoon a crowd of several hundreds 'assembled round the gaol , provided with axes'. In Yarmouth, Hereford, Greenwich and Lambeth (we are now in the age of steam, and rapid reliable transport, at least by sea) similar scenes ensued. A full scale riot broke out in an Aberdeen anatomy school in 1832 when a dog unearthed human remains. The School was looted and burned. The crowd, estimated at 20,000 denied access to the fire engine.

By the time the Aberdeen Riots took place at least 16 citizens of Edinburgh had been murdered in order to stock the anatomy school. Burke and Hare gained a poor living in Edinburgh mending shoes. When a lodger at Mrs Hare's lodging house died the pair sold the body to Dr Knox's anatomy school for £7.50. Another lodger fell ill, and was befuddled with whisky , smothered and sold for £10. Fifteen more followed.

The riots, the murders and public opinion meant that something had to be done and the outcome was the 1832 Anatomy Act which was a key issue in the election of 1832. A key figure behind this was Jeremy Bentham, founder of University College London. His idea was essentially that anyone applying to a hospital for treatment was in effect giving permission for the use of their body, in the event of a poor result, being available for dissection, followed by Christian burial. Although forgoing a Christian burial Bentham was publicly dissected at University College in 1828. There is a sub text to this. Anyone applying to a hospital for treatment meant, in effect the poor who could not afford to pay a doctor. Hospital also meant workhouse. After much argument with Peel, the Prime Minister and political manoeuvring designed so that the death rates in the workhouse should not be made public the bill became law. The situation was now this: the bodies of those maintained by the state (i.e. in Workhouses) if not claimed by relatives (for burial at their expense) became the property of the Anatomist. The fate of these bodies had become, and still is, anatomical examination - not dissection. Administration was by an Inspector of Anatomy, working for the Home Office. Unsurprisingly the residents of workhouses, un-consulted, were not happy with the act, but powerless to do much about it. Many evaded examination by signing a declaration that they did not wish to be dissected: the supply from workhouses was unexpectedly low: there were riots: there was scandal, misadministration and indecency and plain mistakes. Burial services and coffins were often rudimentary. Burial clubs became common - like a Christmas Club - pay so much a week for your funeral. Just before World War 1 ten percent of the income of women in Lambeth was set aside for 'Industrial insurance'. There is still a dread amongst the older generation of a 'pauper's funeral' The only change to the act, however, was in response to repeated failure of the anatomists to bury remains within the stipulated period: the period was extended in 1871.

We operated under the 1832 act until very recently. What has changed? Well, the workhouse has gone. From the Anatomists point of view this meant that the supply of material declined: there were shortages in the 1920s. The Inspector of Anatomy at the time suggested 'a modest fee of five shillings' to officials in mental homes - by then the main source of supply.

At this point something odd happened, perhaps allied to the rise of socialism and atheism. There was continued outcry against the bodies of the poor being used, and against token burial services in token coffins. But there was also a rise in donations. From almost zero before world war one, to 5% between the wars, then rising again after world war two to almost 100%. The cause of this is unknown: it parallels a rise in cremation rather than burial and perhaps tokens a change in our attitude to our bodies. Perhaps it parallels the demise of the paupers funeral and the idea that poverty and misfortune could qualify a person for dismemberment against their will. Who knows ? But all bodies dissected in Leeds are now donations.

So what does donation entail? Around 100 people a year from the area contact us wanting details of this philanthropic act. We ask only that a letter stating their wish is placed with their effects. At the time of death we are informed and, if the next of kin agree, the body (which is technically their property) is donated to us. If the donation is accepted by a Licensed Teacher (reasons for refusal include post mortem examination, notifiable disease, gross over- or underweight and certain diseases which change the anatomy of the body). The deceased , having been certified as dead, is collected by an Undertaker and transferred to our mortuary. After a statutory period (there are constant stories in the papers of the certified dead waking in the mortuary) the deceased is given a coded label, undressed, shaved and embalmed with a mixture of alcohol, formaldehyde and phenol in water. Embalming fluid is introduced via an artery, usually the femoral artery in the leg. The process of embalming renders the cadaver sterile, discourages decomposition and prevents the spread of disease. The cadaver is then wrapped an placed in a refrigerator until used.

Certain provisions of the Anatomy Act are taken very seriously in this University.

First we are obliged, after a statutory period, to bury or cremate all the remains of Mr X, unless he has given consent that certain portions are retained as museum specimens. We do not wish to confuse bits of Mr X with bits of Mr Y. At this point we should distinguish between the kinds of anatomical specimens you will see

* first of all the cadaver which students may dissect.
* Secondly the prosection, where the dissection has already been done for you. These are either wet specimens i.e. embalmed or plastinated - embedded in a plastic resin which leaves them flexible but dry to the touch.
* Thirdly the museum specimen or pot, which, as it name implies is sealed in a jar.
* Fourthly dried bones
* Fifthly radiographs, CAT scans etc.

In order to keep all pieces of Mr X together the rule is that he stays on the same table until finished with. Parts will then be removed in labeled bags and placed in the mortuary. After a statutory period all remains will be collected together, placed in a coffin and buried or cremated according to the wishes of the deceased. Members of staff attend funerals as a mark of respect. We must also remember that Mr X was someone's husband, father, uncle, lover. and treat him accordingly.

A few rules of elementary hygiene are also necessary in anatomy classes. Wear a white coat, tie your hair back if it is long and wear plastic gloves if you wish. You will not catch anything from the corpse, but the embalming fluid irritates some people's skin and human fat smells. If you come to classes in street clothes you are guaranteed a seat on the bus home. Do not eat or drink in anatomy class. The other resource which we have not mentioned is you, the student. You are young, healthy and alive. Wherever anatomy can be demonstrated on the living we do so. You will therefore find yourselves called upon to act as models for your fellows for all the bits conveniently seen from the outside - surface anatomy. This means that you should be appropriately dressed for the relevant classes and be prepared to remove clothing as necessary. So we are back to Richardson's problem of suppression of physical and emotional responses. We try to help you with this by a first class which is really compare and contrast yourselves with cadavers: we hope that this will breed familiarity, and familiarity will in turn breed respect rather than contempt.

Introductory Anatomy: Terminology

What is anatomy?

Anatomy is the study of the structure of the body. Derived from the Greek to cut up: the Latin 'to cut up' gives us dissect.

Structure determines function and vice versa. Understanding the links between structure and function is intellectually more satisfying than learning lists, and makes long term retention easier. The abnormal patterns seen in disease are also related to anatomy: the transmission of stress from outstretched hand to trunk determines the location of skeletal fractures. The structure of the mouth determines the route of puss from a dental abscess. During your course we shall continually stress both the relationship between structure and function and the relationship between structure and disease.

Subdivisions

Under the general heading of anatomy are several subdivisions.
Embryology examines development of adult structure from fertilised ovum
Cytology deals with the structure of individual cells
Histology deals with aggregations of cells, tissues, or aggregations of tissues, organs
Neuroanatomy deals with the elaborate connections of nerve cells
Gross anatomy deals with those structures that can be seen without a microscope.

Methods of study

Dissection of a fixed cadaver is the most important tool of anatomists. The dissection may be done by you, the students (and you will have opportunities to practice this skill during the course) or by someone else on your behalf, to produce prosections which show particular regions or features. Prosections save you time, but I suspect that dissection leaves a longer lasting impression of structure.

Living anatomy is the observation of the living body at rest or in action. This has both drawbacks and plus points. Our own bodies (or those of colleagues) are always available to see and feel, and we are younger and more muscular than dissecting room specimens, who are a. dead from natural causes and hence b. usually old and c. embalmed. Some of your patients will be old, but few will be dead or embalmed. So the examination of a patient is an exercise in living anatomy. Living anatomy is sometimes called surface anatomy, because that is what we see - so the obvious drawback is that some parts cannot be seen or felt in the living.

But instruments do exist to allow us to extend the view from the outside on patients. These are usually called -scopes: endoscopes, proctoscopes, bronchoscopes etc. all allow further examination. Nowadays these are often fibre optic devices aided by computer visualisation, and can allow a good view of the gall bladder or the inside of the knee joint.

We can also add a range of indirect imaging techniques. The first of these was probably radiology, the directing of a beam of x-rays at a subject and the measurement of the intensity of what passes through, usually by means of darkening a photographic plate. Different tissues absorb radiation to different degrees, and the pattern of densities can record position shape and size of bones, fat, gas filled structures and so on. Interpretation is often a little difficult because structures at some distance from the source are magnified as the rays diverge and all structures are in focus, and so appear piled on top of each other in two dimensions. A plain radiograph can be enhanced by filling relevant bits of the patient with contrast medium, which is opaque to x-rays. This can be injected into a blood vessel or swallowed to outline parts of the gut.

Radio isotope imaging is a variant of this where the contrast medium is replaced by a radio labeled substance avidly taken up by the target tissue - for instance radio iodine can be used to target the thyroid gland. Tomography, is a newer technique in which source and photographic plate are moved in relation to the subject. Computer Assisted Tomography (CAT) is an even more sophisticated technique in which both x- ray source and detector (replacing film) are moved around the body, producing a data stream which is interpreted by a computer as a series of images equivalent to cross sections through the body at fixed intervals. The drawback is of course that X rays are now known to be harmful, inducing mutation and tissue damage.

Alternatives include:

- ultrasound which reflects from boundary layers between tissues of different densities
- magnetic resonance imaging (MRI) produces images according the atomic structure of their major components, by subjecting them to a strong collapsing magnetic force. Again pictures equivalent to cross sections of the body are produced.

We must also not neglect comparative anatomy. Man is an animal and his structure is often more easily understood with reference to his relatives. For instance the skull contains air sinuses: two alternative theories suggest that these may a. reduce weight and b. act as resonators for the voice. Comparative anatomy tells us that other vertebrates have sinuses, even those which make no sounds. Birds such as geese, which make long migratory flights, have extensive sinuses, in the skull and elsewhere.

Vocabulary

Anatomy has a very specialised vocabulary, much of it inherited from Latin, Greek and Arabic, and used in a very precise way. Medical students usually double their vocabulary during training, and most of the new words will come in the next two years.

There is a standard list of terms, in Latin, which has the disadvantage that virtually no-one uses it. More often we use an anglicised version of these names. Our clinical colleagues either use alternative versions or outdated ones (depending on when they trained). And on top of this is the so-called eponymous nomenclature, calling things after their discoverer, or your boss or folk hero. This is frowned upon as it is unhelpful - Madonna's ligament or Minogue's disease doesn't tell us much about it.

Major parts of the body

Anatomical usage follows general for most of the main parts, head neck, trunk. The limbs are a little different. The Anatomist calls these the upper and lower limbs, and arm means between shoulder and elbow, and leg between knee and ankle. We subdivide the trunk into thorax, above the diaphragm and abdomen, below it.

The anatomical position.

For descriptive purposes the body is always imagined to be in the anatomical position, standing erect, arms by sides, palms of hands facing forwards. In this position directions are given by superior, inferior, anterior, posterior.

These are equivalent to the zoologists cephalad, caudad, ventral and dorsal. Thus the eyes are always superior to the mouth, even if the patient is lying down or standing on his head. These terms are not quite equivalent to above, below, in front of and behind. To a layman an acrobats feet are above her head when she is dangling from a trapeze: to an anatomist they are inferior.

Other dimensions are referred to the midline - median, medial or lateral, or to their closeness to the body surface, superficial or deep. In the limbs structures near the trunk are proximal, those further away are distal. We have a problem with the hands and feet: the palms of the hands resemble the soles of the feet and the thumb is equivalent to the great toe. But the palmar surface of the hand faces anteriorly and the back is dorsal. In the foot we defy logic and call the inferior surface plantar (equivalent to palmar) and the superior surface dorsal, even though it faces upwards. But we are still not out of the wood because the great toe is medial but the thumb is lateral. To get around this the term preaxial is often used to describe the thumb or great toe side. Postaxial is the little toe or little finger side. The axis referred to runs to the tip of the middle finger or the second toe.

The other small problem, the penis, is described in it's erect position, so that its dorsal surface faces anteriorly and superiorly when detumescent.

We also need to define planes, mutually at right angles. The horizontal plane is clear enough: the other two are a little less so. The sagittal plane (L. sagitta, an arrow) probably refers to the sagittal suture which runs from anterior to posterior in the newborn skull, and has an arrowhead in the form of the frontal fontanelle. Coronal is also difficult since it means crown, and I always think of a crown as being horizontal. But this is an older usage, as in the crown of an arch or a tooth, or the road, meaning something more like a halo.

Once again these refer to the anatomical position.

Now that we can describe the body at rest we can also deal with movement.
abduction is movement of any part away from the midline in the coronal plain
adduction is return to the midline flexion is moving anything in the sagittal plane
extension is straightening it again.
lateral flexion is bending in the coronal plane
rotation occurs around a vertical axis, or the main axis of the limb. If we rotate the head to the right we end up facing right. For the limbs we still use the displacement of the anterior aspect i.e. lateral rotation moves the palm laterally. The shoulder is a good joint to illustrate movement because it is so free. The slide shows what we can do, and how we describe it.

Hand and foot again pose problems because of their distinctive orientation. The hand has a rather unusual movement whereby the thumb can be brought to lie medially: in fact this crosses the bones of the forearm. The anatomical position of the hand is called supine, the reverse prone, so this movement is pronation reverse supination.

Abduction and adduction of the digits are refereed to the axis of the hand or foot, which remember pass through the middle finger and the second toe. We also have a thumb problem. Finger nails are posterior, but that of the thumb lies at right angles to the others. The thumb normally lies with its palmar surface facing medially. Flexion and extension are thus in a coronal plane while abduction and adduction are sagittal. The thumb also has another important movement, opposition which brings its palmar surface in contact with the palmar surface of the fingers.

The feet also bring problems, so we talk of dorsiflexion and plantar flexion and, a unique foot movement inversion and eversion as the soles are made to point towards each other or away.

Variability in anatomy

One important fact which an anatomist must recognise is that no two of us, even identical twins are exactly alike. The structure of the body varies with

- age
- race
- sex
- genetic diversity
- environmental history (especially during growth)

The anatomy in most textbooks is the commonest pattern in adults, usually from Europe or N America. Good texts will give variations if common. Remember the body is always right: often a bizarre variant never seen before will work well for 70 or 80 years. In one year we had difficulty finding a text book pair of kidneys, because they are so variable. Because of this variation you should always look at a number of bodies, prosections or colleagues.

Age. Although this is a whole field in itself it is important to recognise the commonest changes due to age, since you will be looking mainly at aged cadavers and young, fit adults. Bear in mind that an 80 year old will differ in these respects:

connective tissue - less elasticity - wrinkles
cartilage - less elasticity - degenerative changes such as osteo-arthritis with associated changes. Costal cartilages often replaced by bone: bony spurs

develop in unusual places.
bone - becomes brittle, reduced in size with less activity
muscle - ditto, plus deposition of fat.
heart and blood vessels - arteries become tortuous, walls become furred up with atheroma. Left ventricle is enlarged as consequence of load. Veins often varicose.
nervous system - Often small strokes will cause paralysis and reduction in size of some muscles.
Race- This is a tricky one because of its emotive content, and because of the difficulty in defining race since the invention of the bicycle, steamship, jumbo jet etc. have done much to cause intermingling. Carefully noting the distinction between racism and Racialism we can say that there are obvious differences in skin and hair colour, hair type, eye colour, etc. and some subtle but small differences in anatomical measurements.

Sex - The two sexes obviously differ in their reproductive organs: they also differ in many other respects: although variability is quite large within a sex height, weight and muscle mass will differ significantly. Males also have narrower hips and broader shoulders. Females have more dermal fat, distributed differently. Facial and body hair also differs.
Genetic and other variation - congenital anomalies - There is quite a high level of genetic and environmental variation which leads to the presence of extra fingers, a single kidney, or an extra rib or so. This may be genetical or due to the exposure of the fetus to something unpleasant during pregnancy - x-rays, medicaments, viruses. Superimposed upon this is the variation due to habit - a regular swimmer will have a better developed upper body than his or her classmates: a smoker may have inferior lung capacity.

Introductory Anatomy: Bones

Anatomists talk about both bone and bones. The former is a type of connective tissue made up of cells suspended in a matrix: the collagenous matrix in bone just happens to be heavily impregnated with minerals. You will learn about bone cells elsewhere, but here is a picture of a cast of one, just to prove they exist . This osteocyte has characteristic long processes which run through the bone putting it in touch both with other cells and with blood vessels and nerves. Bones are discrete organs made up of bone tissue, plus a few other things.
The main misconception about bones then, is that they are made up of dead tissue. This is not true, they have cells, nerves, blood vessels and pain receptors. Bone constituents, organic and inorganic matrix and cells all turn over at a fairly rapid rate. If we treat a bone with various solvents we can remove the inorganic matrix and leave the flexible collagen. Or we can burn a bone and leave a hard brittle residue.

The true structure of bone lies somewhere between these images. In tensile strength bone is rather like cast iron, although around 1/3 of the weight, in bending stress it behaves like steel, although only half as strong and in compression it can withstand the forces exerted by a running man (equivalent to a dead weight of 270kg). Even in standing the compressive force on the hip joint, which you might expect to be half the bodyweight on each side, is multiplied by a factor of around six by muscular pull, since we are not in equilibrium when standing.

Determination of shape

The shape and structure of bones is governed by many factors, genetic, metabolic and mechanical. Genetic determination of primary shape can be demonstrated by organ culture of bone rudiments, which subsequently grow into recognisable bones, i.e. roughly the finished shape in all major respects. Fine tuning is by muscular action. The muscles are active in utero, although it is difficult to isolate their effect at this stage. After birth, however, and up to adolescence there is a correlation between activity and growth. this is seen in reverse if we look at people who are bedridden, or who have paralyses (such as poliomyelitis).

Metabolic factors are also important: calcium, phosphorous, vitamins A,C and D and the secretions of the pituitary, thyroid, parathyroid adrenals and gonads are all involved. Dwarves and giants are controlled by aberrant hormones, but there is much variation in normal height. Absence of adequate supplies of vitamin D may lead to rickets, and absence of calcium in the diet to week bone liable to fracture.

Function

1. As a lever. The bones of the upper and lower limbs pull and push, with the help of muscles.
2. As a calcium store. 97% of the body's calcium is stored in bone. Here it is easily available and turns over fast. In pregnancy the demands of the fetus for calcium require a suitable diet and after menopause hormonal control of calcium levels may be impaired: calcium leaches out leaving brittle osteoporotic bones.
3. Protective? This is often quoted in books: in fact protection against outside forces is rarely needed, and if it is we usually wear a cycling helmet, or a crash hat, or a hard hat. Or sit in a very strong structure like a formula 1 carbon fibre tub or a Volvo. So the bone can't be that good. In practice these are exceeded by the almost continuous large forces exerted by our own muscles. Respiratory movements need ribs. If a thigh bone or a humerus fractures the pull exerted by the muscles, even though not in active use, will be enough to overlap or otherwise displace the broken ends and we need considerable force, traction, to reduce the fracture i.e. to un-overlap the bits so that they can be lined up. The force exerted by the masticatory muscles is sufficient to support the bodyweight.
4. As a marrow holder. This is secondary to production of maximum

strength for minimum weight: the cavities produced in unstressed areas (like the holes in the tubes of a bicycle frame) are used for marrow, or in some places (mastoid) just for air storage. The saving is small in man but considerable in an elephant. Occurrence of bone in two main forms, compact and cancellous. Both can be seen in our old lady's vertebra. That section was produced like this. Around the outside is a layer of strong, hard, heavy compact bone. In the middle is a branching network of cancellous or trabecular bone which usually, like iron filings, follow lines of force. Marrow sits in the interconnecting cavities between these plates or rods of bone.

Origin of bone is again in two main forms. Some bone (in broad terms almost everything except the top of the skull) is preformed in cartilage - replacement or endochondral bone. Details will come in histology lectures. In the skull and one or two other places, however, bone forms direct in membranous connective tissue - membrane bone.

Look at the history of the skeleton to see why. Calcified skeletal tissues replaced silicacious in the Cambrian period, presumably because physiological changes either in the beasts or the oceans in which they lived allowed retention of Ca ions. Brachiopods, nautiloids, trilobites gradually converted. Later the first vertebrates had bony scales embedded in their skin - those around the mouth incidentally form the primitive basis of teeth. In some lines these scales fused to form bony carapaces. These carapaces are retained over our heads as skull vaults. Later the rest of the skeleton, vertebrae etc., which were cartilaginous also became bony. This explains the distribution and origins of membrane and cartilaginous bone. The surviving membrane bones, notably in the head and part of the clavicle (a later invention made up of 2 fused bones, one membranous one cartilaginous) are bits of dermal shield.

Whether in membrane or cartilage centres of ossification marked by the appearance of calcified matrix appear over a long period of time, some in embryonic life, others in fetal and yet others well into the postnatal growing period. Many bones ossify from one centre, others from a group, of which one, the primary centre of ossification, is usually central and early, and others, secondary centres, later and often peripheral.

Classification of bones

The skeleton is made up of many bones which change in proportion between man and his close relatives but are easily recognisable. The easiest way to classify bones is by shape.

Long bones

Typical of limbs, and a good place to start. They consist of a central, usually hollow, tubular region, the diaphysis linked to specialised ends (epiphysis) by a junctional region (metaphysis). Look at the shaft first. Tubular, a bit like a bicycle frame tube. Galileo was the first to write sensibly about this, noting that a hollow tube was stronger, weight for weight than a solid rod, and that the dimensions had to be related to body weight rather than area: so the bones of an elephant have to be proportionally broader than those of a man. In some bones we can see adaptations for specific forces. For example the wing bones of vultures and other large birds have strengthening that makes them very like bridges: it is a sobering thought that the first vulture predates the first girder bridge by some millions of years. The diaphysis has layers of bone arranged like plywood for strength. The cavity is filled with bone marrow (red and active in children, yellow, fatty and inactive in adults). The shaft walls are made of compact hard bone, and thickest in the middle where forces are greatest. If these forces are too great the shaft may fracture. Young bones have less calcium and are pliable, so fracture raggedly and partially (greenstick): older bones will fracture transversely or spirally according to force applied. Fractures usually heal spontaneously, albeit rather slowly in some cases, but the broken surfaces need to be manipulated into the right place and may need to be held with casts, pins or wires.

Towards the ends of the shaft the marrow cavity tends to be wider and filled with trabecular bone, arranged along lines of force which has a skeletal function in its own right and supports the marrow.

The ends of the bone are specialised to allow growth with as little loss of strength as possible. The epiphysis permits this, but looks complicated. Lets go back to the fish long bone and try to understand the logic underlying the structure. Growth must occur both at the end of the shaft (A) and over the surface of the joint (b). The fish accomplishes this by ending the bone with a simple plug of cartilage. This works until the bone has to bear weight, when the large, floppy cartilage becomes an embarrassment. The first modification, seen in the chelonia (turtles and tortoises) is that the surface becomes curved (marrow cavities first seen in amphibians). The new radially arranged cartilage is still strong but less bulky. The next problem is when the end is no longer hemispherical: the structure is then less strong, and continual reshaping is necessary with growth. These problems can be overcome by producing a secondary centre of ossification, already mentioned, - forming another lump of strong bone in the epiphysis. This is popular, occurring in at least seven groups of land vertebrates. We see secondary centres at the ends of most long bones, often more than one per end if the shape is complex. These ultimately fuse with the main shaft in a process known as closure of the epiphysis. Which strengthens the bone but ends the possibility of growth. This is a useful for forensic/medical purposes, but does not occur in a very regular way.

Short bones

Short bones are found in the wrist and ankle, carpals and tarsals respectively. They have no shaft, as they do not increase dramatically in size in one dimension during growth, and tend to be cuboidal in shape. They are rather like a Malteser in construction, with cancellous bone in the centre and a hard outer shell of compact bone.

Flat bones

Flat bones like those of the cranium or the scapula are sandwiches of spongy bone between two layers of compact bone. They are usually curved, so we can refer to an inner and outer table with diploe between them. These diploe, especially in the skull, may become pneumatised, i.e. filled with air. A ring of facial sinuses around the nose may become infected, leading to sinusitis.

Irregular bones

Any bones which don't fit these arbitrary categories (bones of the face, vertebrae) are referred to as irregular.

Sesamoid

Sesamoid bones are interesting because they occur in tendon, especially where a tendon turns a corner, and is thus exposed to friction. We shall come across these again when we talk about muscles.

Surface markings of bone

We can often glean clues about what is going on around a bone from its surface. In places, like joint surfaces, the bone will be covered with smooth articular cartilage. This falls off in preparation but leaves the underlying bone smooth too. Bone is constantly growing or being reshaped, and this takes place on the surface. At high magnification we can see, in a dried bone, what it was up to the point of death. This picture shows a hole for a blood vessel, a foramen. Around roughly half its diameter the collagenous bone is rough, the other half smooth. The rough is resorbing bone, being eaten by large osteoclasts which leave pits and the smooth is depositional, bone being formed. This indicates that the foramen was on the move as the bone grew. Other areas also show deposition and resorption: these would be building up and hollowing out respectively. On a macroscopic scale these effects can be seen as points of attachment to the bone - of ligaments, tendons or the fibrous insertions of muscles. All these structures transmit forces, and demand a well organised junction. Any part of this structure which has deposited calcium will appear as a bit of bone. Within the bone we often see rows of trabeculae or thick ropes of collagen, Sharpey's fibres running across the marrow cavity to insert in the cortical bone opposite. Blood vessels and nerves similarly have canals.

The various lumps for fixing things to have different names according to shape, usually derived from a dead language. There are lots of these, but common ones are:

- lumps and bumps
- process
- spine - if sharp
- tubercle - if rounded
- cornu - if horn shaped
- hamulus - if hooked
- crest - ridge
- line - low ridge
- depressions and holes
- sulcus - groove
- canal - tunnel
- foramen - hole
- fossa - depression
- articular surfaces
- facet - if small
- condyle - if rounded
- epicondyle - if near a condyle
- trochlea - if pulley shaped

Introductory Anatomy: Joints

Joints are accordingly classified

1. fibrous and cartilaginous joints where two bones are separated by a deformable intermediate
2. synovial joints where one surface slides freely over another.

Fibrous joints. We have already mentioned the joint between the bony shaft and cartilage at the ends of long bones. This is a synchondrosis, a cartilage sandwich with bone on either side: bone and cartilage fit together perfectly and the whole thing is cup shaped. If movement occurs the growing bone will be damaged (slipped epiphysis) and this is countered by putting in a long nail to fix it again.

Sutures: are limited to the skull. They resemble a synchondrosis, but with fibrous tissue instead of cartilage between the bones. Sutures are necessary for skull growth: consequently well marked in the young less so in the adult. The only movement in sutures is at birth when the cranial bones overlap to allow passage through the maternal pelvis. After this movement is discouraged by increasing complexity of the suture, which becomes serrated or denticulate. Later in life, when growth is complete they fuse.

gomphoses: are peg and socket joints as seen between teeth and jaws. The joint is maintained by the periodontal ligament which gives only a little to act as a shock absorber when we bite on a ball bearing.

syndesmosis: only one of these in the body, the inferior tibio-fibular joint. In this type there is a little movement, limited by a tight ligament. Since many joints are limited by ligaments this is probably a special definition we can do without. symphysis: two bones united by cartilage, but designed to give a bit. The symphysis pubis with ligaments and fibrocartilage is normally closed, but opens in childbirth due to hormonal influences.

Synovial joints have different parameters. Joint surfaces almost in contact but discontinuous, as a great range of movement is often possible, and the surfaces slide over each other. The sliding surfaces are covered with a thin layer of cartilage. This gives a coefficient of friction of <0.002. The joint cavity is sealed by a synovial membrane which secretes synovial fluid, a lubricant and nutrient. Around this, in turn, is a tough fibrous joint capsule which keeps the ends of the bones in proper orientation. This is often locally thickened to form joint ligaments. The synovial cavity is very small between articular surfaces but larger round the edges where it may form a bursa, a sack-like extension which may be in contact with the joint cavity.

Various inclusions may be present in the joint cavity: a tendon may pass through, sheathed in synovial membrane. Fat pads may be present, packing the large gaps which occur in some joints between bone ends. Pieces of cartilage are also found, in addition to articular cartilage. These may form:

1. a labrum or lip deepening a bony socket
2. menisci - incomplete discs or crescents increasing the size of articular surfaces
3. complete, or nearly complete articular discs of fibrocartilage. This will convert a joint into two in parallel, which can then move in independent directions. The temporomandibular joint of the jaw is a good example of this.

Evolution of synovial joints

Not surprisingly such an efficient mechanism is widespread and found in most vertebrates from lungfish onwards. In lungfish a synovial joint is found only in the jaw, with most other joints being simpler: symphyses with a cartilaginous region between them. We can imagine that this could be made more flexible if the cartilage had fluid filled holes in it, which might join up into a single cavity surrounded by a fibrocartilaginous ring. Large pressures exerted on the bones might then bring the cartilage-covered ends into contact, in conjunction with a developing system of lubrication. This is no

more than a good story, but we can find most of the postulated intermediates in lower vertebrates, with the synovial joint coming into its own at about the time of the conquest of land.
Movements in synovial joints. These can be very extensive the shoulder joint being particularly free and able to move around three axes.

Various schemes of classification of synovial joints have been used and will be found in different textbooks.

1. Complexity Many joints possess only two articular surfaces and are therefore simple. Usually one surface is convex or larger than the other and termed male. Compound joints have more than one pair of articulating surfaces (e.g. the elbow has two male surfaces on the humerus which articulate with female surfaces on radius and ulna) and are thus compound. Complex joints have an intracapsular disc or menisci.
2. Degrees of freedom A joint which moves substantially in one plane (like an elbow) is uniaxial. One which moves in two planes is biaxial, one which moves in three is triaxial. A ball and socket is multiaxial, but is equivalent to a triaxial as it has three degrees of freedom i.e. all movements can be reduced to XYZ axes. Not a good classification as there are often small but vital movements in other planes (e.g. knee rotation at end of flexing) and cannot take account of sliding movement.
3. Shape Probably the most widely used classification, but still tries to simplify joint surfaces hinge joints: permit flexion and extension (knee) pivot joints: allow rotation (superior radio-ulnar) plane joints: have flat surfaces and allow gliding in several directions (carpus and tarsus) condylar joints: usually regarded as two hinge joints with separate articulations (TMJ) saddle joints: have surfaces shaped like two saddles - allow movement in two planes at right angles and a little rotation (base of thumb) ball and socket: allows very free movement around any axis through ball (hip) ellipsoid: ball and sockets which are not round : rotation therefore impossible (radiocarpal joint)
4. Functional approach. This is the best classification as regards understanding what is going on. All above classifications are approximations and have holes in them which fit uneasily. First classify joint movement. This is always made up of:-
   * gliding - of one surface over another- slide
   * angulation - flexion, extension etc. - roll
   * rotation about axis of bone - spin

Movement always occurs at articular surfaces, which are never planes nor spheres nor cones but always spheroids - egg shapes, either male or female i.e. convex or concave. A point moving between A and B on a surface can take the shortest great circle route a chord, or can take a longer, prettier arc. Any movement can be described by a trigone (a bendy triangle) or three arcs. The imaginary point which traces these movements is the end of the axis of rotation. In the simplest case this is the end of the long axis of the bone: for something like a femur it obviously isn't. Lets try this on a real movement, extending the knee. If we hold the tibia still and move the femur extension has three bits.

1. the femur rolls on the tibia
2. the femur slides posteriorly
3. the femur spins to lock the joint.

The third of these is most important because it tells us something about how joints work. Take an egg and cut it in half. The resulting curved surface has a variable radius of curvature. If we try to fit this to another spheroid we see that it only fits well at one point. Elsewhere there are wedge-shaped gaps and smaller areas of contact. Joints exploit this: the position of best fit, or close packed position usually occurs at the end of the range of habitual movement. As a joint approaches this position ligaments are stretched and often some spin is imparted by them to screw the joint home. In this position the joint is virtually abolished: in practice it is only fully reached under strain and may damage articular surfaces and pull ligaments. So usually it is approached but not realised. This position is comfortable because it uses little muscular energy and can be maintained for long periods. The loose packed position is also important because it allows

1. loosely fitting surfaces to spin, roll and slide
2. a reduced area of contact, so little friction
3. wedge shaped gaps, continually changing circulate synovial fluid like a peristaltic pump.

Limitation of movement is also important. Usually achieved by

1. tension in ligament, which have strain and pain receptors
2. tension of muscles around a joint - passive resistance to stretch followed by reflex contraction when stimuli from mechanoreceptors becomes critical. These explain Hilton's law: that joints and the muscles acting on them share a nerve supply. Paralysis of muscles thus affects joints. In spastic paralysis muscle tone is increased and movement restricted. In other paralyses joints become lax, flail joints or actually disrupted. Charcot elbow in syphilis.
3. Running out of articular surface.
4. approximation of soft parts.

Muscles & Nerves

Having looked at the bones of the skeleton and the joints between them we logically move on to consider the muscles which move the bones and then the nerves which control them. Muscle, however does other things besides moving bones. It is a contractile tissue, divided on histological structure into three types:

* skeletal or striated. Under direct (Voluntary) nervous control
* cardiac, also striated but specialised and confined to the heart
* smooth or visceral. Not under direct (voluntary) nervous control. In walls of alimentary tract, blood vessels, arrector pili - slow and sustained response.

Form and function

* Smooth muscle usually occurs in flat sheets, sometimes wrapped around a viscus like a gut in circular and longitudinal layers, or arranged as a sphincter to close off a tube (as in the anus).
* Skeletal: so called because often attached to bone, but not invariably. This is what the layman thinks of as a muscle. Muscle means little mouse in Latin, from the fancied resemblance of the muscle body contracting beneath the skin. This contractile body, the muscle proper, is usually attached to two bony points. Attachments may be
    o tendon
    o aponeurosis
    o fleshy

Tendons are an integral part of muscle, virtually invariable in length. Made of collagen fibres with occasional flattened fibroblasts it is wonderfully boring stuff which resists stretch and is flexible, so it can turn corners. Because it is so avascular it appears white in life and heals very slowly: this is why damage to the large tendon in the heel, the Achilles tendon is so crippling for a sportsman (as it was, incidentally, for Achilles).

Tendons take the form of cords or strips, circular in cross section, oval or flattened. They are made up of bundles (fascicles) of collagen fibres, mainly parallel and often large enough to see with the naked eye, and striated in appearance. Around the outside is an epitendineum with elastic fibres, which obviously causes a little drag as tendons run through connective tissue. Where they have to move independently of other tissues various friction reducing devices are used. The tendon may run over cartilage, or over a sesamoid bone such as the patella, or a bursa may be interposed. This bursa may be elongated and folded around the tendon to form a sheath. A very flattened tendon is often called an aponeurosis neurosis because it is white like nervous tissue. This usually has the appearance of a flattened sheet of collagen fibres, or often several sheets running on each other in different directions like plywood.

A fleshy insertion is what it says, muscle joined to bone without the intervention of a frank collagenous tendon or aponeurosis. The collagen is still there, but in amongst the muscle fibres, or forming a very short tendon

Origins and insertions

Muscles are often said to have an origin at one end and an insertion at the other. The origin (the one that moves least on contraction) is often proximal, the insertion distal. Often a muscle arises from more than one place: it is then said to have two or more heads (biceps, triceps). In some circumstances origin and insertion can be interchanged, so it is easier to talk of attachments.

Forms of muscles

Wide functional variation in terms of size and shape according to job done. The size of the functional component, the muscle fibre varies from 10-60*m in diameter, and mm to 15-30 cm in length. Diameter, length and arrangement of fascicles (bundles of fibres) varies from muscle to muscle: fine bundles in precision muscles, coarse ones in power muscles. Fascicles may be parallel, or oblique or spiral according to position of attachments. Lets look at some variants and see if we can explain them.

The simplest is probably the strap muscle which has a fleshy, wide attachment at each end. We can make this long and narrow, so long as the maximum length of the muscle fibre is not exceeded. If it is, we need fibres in parallel, with tendinous insertions between groups. The range of contraction depends on the length of a muscle but its power depends on how many fibres we can pack in. Strap muscles thus have a good range but low power: to get more power we make the muscle fusiform i.e. three dimensional. This often transforms the flat attachment into a tendon with a circular cross section. The muscle fibres are often concentrated at one end, but will work just as well if they are digastric i.e. have two bellies. another way to increase power is to produce more heads, in effect two or three or four muscles pulling the same tendon.

Having more than one head results in muscle fibres pulling obliquely on the tendon. This can often balance out, but in a unipennate muscle, where fibres insert all along one side of a tendon the resultant force is the result of two vectors: sideways force is cancelled out in a bipennate or multipennate arrangement. Multipennates are fairly common compound muscles with a short range but plenty of power.

Spiralised muscles are a special case which not only pull the attachments together when they contract but try to untwist. A similar twisting is sometimes arranged by wrapping the course of a muscle around a bone.

Action of muscles

Muscles do not suddenly snap from a state of relaxation to one of contraction. At a given time some functional units (motor units, groups of fibres of various size) will be contracting, some relaxing and some in stasis, the resultant providing muscle tone. If the proportions doing each stays constant, so will muscle tone, although individual units will cycle.

When an individual fibre contacts it tends to approximate its ends, but whether or not this results in contraction depends on the force generated and the forces opposing contraction. The net result for the whole muscle may be contraction, relaxation or stasis.

A muscle trying to initiate contraction is opposed by

1. passive internal resistance of muscle
2. ditto articular tissues
3. opposing muscles
4. opposing soft tissues
5. inertia of whatever it is trying to move
6. load
7. gravity

If the force generated exceeds the sum of all these then the limb is accelerated from rest: once moving a smaller force will keep it moving. A muscle doing this is sometimes called a prime mover or agonist. It is often opposed by antagonists which can stop the movement. When both groups act together nothing moves, or the movement is moderated or controlled. If the movement is abolished the real result is that the joint across which the muscles act will be stabilised - often cannot be done wholly by close packing or gravity - which are preferable as they use little energy. Movement is always opposed or aided by gravity, and this is used wherever possible. In placing a weight on a table the extensor of the arm is not triceps but gravity, controlled by slow relaxation of the flexors.

The action of a prime mover often exerts a little unwanted movement. For example the flexion of the fingers by long flexors also flexes the wrists: this is opposed by wrist extensors.

Muscle mechanics

In a simple arrangement of two bones joined by a muscle the pull of the muscle can be resolved into
a. swing - tending to move the mobile bone
b. shunt - compressing the joint
c. spin - rotating the mobile bone

The relative size of each component is varied by moving the attachments of the muscle. Obviously the largest swing is best for initiating movement - spurt muscle: large shunt will allow a mobile bone to be loaded by compressing the joint and large spin can be used for prime movement or as a synergistic soaker up of unwanted rotation.

Nerves and muscles

Control of muscle action is by the nervous system. Nerves are in touch with muscles by motor end plates which convey a stimulus to contract. They are also in touch with tendons via receptors which measure stretch and connective tissue by other receptors for pressure. These are referred to as efferent, if they are taking a message to a tissue and afferent if they are taking a message to the spinal cord and hence the brain. The brain and spinal cord is referred to as the central nervous system (CNS), and the connections as the peripheral nervous system (PNS). Different terminology applies for similar structure according to where you are:

	CNS	PNS
bundle of axons	tract	nerve
accumulation of cell bodies	nucleus (brain) grey matter (spinal cord)	ganglion
myelinating glial cell	oligodendrocyte	Schwann cell

The peripheral nervous system is thus largely made up of nerves collections of cell processes, their insulating sheathes of myelin and the cells that secrete it, Schwann cells and connective tissue. The cell processes are referred to as efferent, if they are taking a message to a tissue and afferent if they are taking a message to the spinal cord and hence the brain. Almost all nerves contain a mixture of afferent and efferent cell processes. At intervals, ganglia, collections of cell bodies can be found. The CNS is made up of the specialised brain, and less specialised spinal cord. The spinal cord is made up largely of tracts, their insulating sheaths of myelin and the cells that secrete it, oligodendrocytes. In places nuclei, or accumulations of grey matter (collections of cell bodies) can be found.

Central nervous system

Lets look first at the central nervous system.

Brain. Many invertebrate and vertebrate animals have a nerve cord running from anterior to posterior. Almost invariably this is larger at the anterior end, where sense organs are situated. In vertebrates three sets of paired sense organs, covering smell, sight and hearing/balance are located anteriorly and dorsally. Corresponding to these are three outpushings of the roof of the brain containing groups of nerve cells. The primitive smell brain, sight brain and hearing brain have undergone many changes but are still recognisable in man. The smell brain has become the cerebral hemispheres, the sight brain the tectum (less important in mammals than birds) and the hearing brain the cerebellum. Interestingly in the ventral midline a downpushing produces the infundibular stalk - the link to the endocrine system.

Spinal cord The spinal cord is made up of two distinct regions, grey matter and white matter which look like this. The white matter is around the outside and the grey forms an H in the middle. The grey matter is made up of accumulations of the bodies of conducting cells, neurones. These cells have long processes which may pass up and down the cord or out into the peripheral nervous system. Through both white and grey matter run different types of non-conducting glial cells, which provide nutrients and wrap nerve fibres in the cord with myelin. The white matter is made up of nerve cell processes, axons, wrapped in myelin which appears white in fresh tissue: confusingly most fat stains turn the white matter black.

Because there are afferent and efferent cell processes we need a way in and out of the cord. The way in is dorsal, the dorsal root which is a continuation of the top limb of the H in each spinal segment. The way out, the ventral root is not seen on this diagram because it is at a different level and tends to be a series of rootlets. If we want to see them both at once we have to make the section thicker. It is convenient in many cases to have the wiring to and from a particular part of the body running together, so the two roots join to form a mixed spinal nerve which runs round beneath each rib in the thorax. We will come to the bump in the dorsal root in a moment. The spinal nerve covers a whole body segment, sending off motor sensory or mixed branches as it does so.

We can now put in the simplest possible wiring diagram. This consists of three neurons.

1. a sensory neuron. The cell body of this is in the dorsal root ganglion, the dorsal swelling I mentioned earlier, made up of thousands of similar cell bodies. A long process comes from a sense organ in the skin and a shorter one runs to the spinal cord. Once in the spinal cord the possibilities are endless: it could go up to the brain or down to another spinal level, but lets keep it simple and say it synapses with
2. a connector neuron whose body is in the dorsal horn and synapses in turn with
3. a motor neuron whose body is in the ventral horn, and whose axon passes out along the ventral root to a muscle, which contracts.

So far so good, but we have only dealt with connection to skeletal muscle. Smooth muscle is wired rather differently via the autonomic nervous system. This is in two parts, sympathetic and parasympathetic. Lets deal with the sympathetic and look at a sense organ in a tendon. This uses all the familiar bits of the circuit plus another part the sympathetic chain. The sympathetic chains, or sympathetic trunks are made up of (originally) segmental ganglia and run antero-medially to the spinal cord. Connections are nowadays made only in some parts of the body - our example is thoracic, between T1 and L2.

The same three neurons are used, but in slightly different places. The sensory neuron is exactly the same except that it synapses not in the dorsal horn, but laterally. The thousands of synapses make up a lateral horn in the thorax. The connector neuron is longer, passing out of the cord and into the sympathetic ganglion via the white ramus communicans.

There are three possible variants from here.

Firstly: the connector neuron synapses with the motor cell body, and the axon leaves via the grey ramus communicans to the smooth muscle.

Secondly: the connector neurone may travel along the cord and synapse in another ganglion: it then leaves, not by a spinal nerve but by a special pathway to travel with blood vessels to, say, the heart.

Thirdly: the connector neurone does not synapse but runs out of the sympathetic chain as part of a splanchnic nerve whose preganglionic fibres synapse in a ganglion near the aorta before supplying abdominal viscera. So only the proportions of the three neurones and the location of their cell bodies have changed. Outside the area served by direct connections to the spinal cord the sympathetic fibres have to run up or down the sympathetic chain first. The other part of the autonomic nervous system, the parasympathetic, is more specialised. Whereas all the body receives voluntary and sympathetic fibres parasympathetic innervation is restricted to some viscera (excepting the adrenal and gonad). Their connector neurones are restricted to certain levels in the brain and to S 2,3,4. You will learn about this in detail elsewhere in the course.

Introductory Anatomy: Circulatory System & Blood

Perhaps the most important thing to remember about the circulatory system is its variability. This is because of the way the circulatory system develops: the early embryo is essentially a blood filled sponge - intricate network. Most of this is removed during development, leaving remnants governed by highest flow and pressure. Its plasticity is also shown by migratory organs: if an organ moves during development eg the kidney it will take its nerve supply with it, but acquire a new local blood supply - successive segmental arteries of the kidney as it rises may persist as 'abnormal' renal arteries.

Sensible place to start is the heart, complicated at first glance so let's reduce it to a diagram: four chambered, atria and ventricles in one way communication. Right half circulates blood from body to lungs, left half circulates blood from lungs around body. This has immediate implications: the pulmonary circulation is rather small, little peripheral resistance, so low pressures needed and the walls of the right ventricle are rather thinner. The left side pumps the same volume against greater peripheral resistance, so the left ventricular walls are more muscular.

There is functional specialisation in the vessels too.

1. Distribution system
Low volume, high pressure system of large arteries which leave the heart: we speak of the arterial tree, trunk, branches, twigs. The branches are always smaller than the trunk and so on. Several branches may come off at a single level, but more often a main trunk gives off branches and continues. Structure is also graded as you pass away from the heart. Large trunks have much elastic tissue in their walls. Repeated distention and contraction of this tends to even out heart contractions into a steady, though pulsatile flow. Smaller branches have less elastic tissue and more smooth muscle offering better control of flow to suit temperature, activity etc.
2. Resistance vessels
Control blood flow at more intimate level - muscular arterioles and precapillary sphincters provide principle resistance to blood flow which governs pressure in arterial tree.
3. Exchange vessels
Capillaries are often composed of a single wrapped cell at any given level. Across their walls occurs exchange between blood and tissue fluids, oxygen, CO2, nutrients, water, inorganic ions, vitamins, hormones, metabolic products, immune substances, even immune competent cells. Capillaries may be plain, fenestrated or sinusoidal - to slow blood flow.
4. Capacitance vessels.
After capillary beds blood is collected in venules which are tributaries of veins. These vessels provide a low pressure blood reservoir through which blood returns to the heart. Veins have the same basic histological structure as arteries, but tend to be greater in cross sectional area at any given level, because of slower flow rate. For the same reason arteries are often accompanied by paired veins, vena combatants.

Veins often have a dead space around them to allow for dilation, so not sheathed as arteries are, but run in loose connective tissue. Because only a little external pressure would stop flow veins are confined to the dorsum of the foot and the back of the hand, and often run on the flexor aspects of joints.

Valves
The tendency for gravity to stop or reverse the flow of blood in veins is countered by valves - pockets in the walls, usually in twos or threes. Reflex blood pours into these pockets, filling them and stopping the flow. They are found where a tributary joins a larger vein, and at intervals along main veins. Most frequent in lower limb, where the effect of gravity is greatest, diminishing as we move superiorly and virtually absent above the heart, where gravity acts with venous return, not against it. Return of blood is ensured by several factors. Smaller veins are continually filled by capillaries, larger veins (especially in the lower limb) are continually squeezed by muscular action, valves controlling the direction of flow.

Exceptions to the rule

1. Portal circulations

These differ from those already described in having two capillary beds. The largest portal system covers the spleen, pancreas, stomach, small intestine. Blood supplying these, having passed through their capillary network ends up in the hepatic portal vein, which drains into the liver and through a hepatic capillary bed, where products of digestion are removed, processed and stored. A second, smaller but equally important portal system is found connecting the brain and pituitary gland.

2. Anastomoses

Arteries do not always end up as capillaries. They often anastomose with other arteries, either of equal (in the brain) or unequal size (elsewhere). In limbs anastomoses are most common around joints: quite clearly they form an alternative route when the main road is obstructed by, say, flexion of the elbow: they will also allow equalisation of pressure. They become more frequent as you get further from the heart i.e. as the arteries get smaller, so that arterioles tend to form a network. If you cut an artery which forms part of an anastomosis it will bleed from both ends. Anastomoses form the basis of collateral circulation. This is important if an artery is gradually furring up: alternative arteries will enlarge to restore an adequate supply. Sudden blockage may lead to the death of the area supplied (avascular necrosis) if collaterals are absent or inadequate. This is seen in the head of the femur, scaphoid after fracture and central artery of the retina, and in coronary arteries supplying heart muscle - end arteries.

3. Vascular shunts.

These are important shortcuts from artery to vein cutting out capillary bed. These are seen as

a. preferential thoroughfares - areas of a capillary bed are deferentially supplied with blood under different demands. Areas are then restricted by closing precapillary sphincters.

b. artero-venous anastomoses - direct connections between arteries and veins, by coiled vessels with a thick muscular coat, which may allow complete closure. These, found in skin of nose, ear, tongue, erectile sexual tissue, hands and feet are temperature control mechanisms, cutting off blood supply to a capillary bed to reduce heat loss, or encouraging it to encourage it (panting dog). Regulation of blood pressure? Maybe.

Absent in newborn, atrophy in old age - so wrap up newborns and grannies.

Lymphatic circulation As well as blood vessels we can also find a system of lymphatic capillaries and larger vessels. Lymph capillaries coexist with blood capillaries in capillary beds, have fenestrated walls and can thus exchange anything from liquids to cells. Most of the fluid which leaks from blood capillaries into tissues returns, but 10-20% doesn't, and would therefore gradually flood the tissues if left (oedema). This is mopped up by the lymphatics,, which shadow the veins and eventually dump lymph, usually via one or more lymph nodes into the blood stream, via the thoracic duct and right lymphatic duct which open into veins in the neck.

As well as fluid this system contains cells, notably phagocytic dustman cells which circulate in the blood, exit via the capillaries, spend time in the tissues collecting anything from dead cells to bacteria, then return via the lymphatic system. Because of this behaviour the phagocytic cells are often laden with bacteria, viruses or diseased cells. Lymph nodes are thus prone to infection and swelling and the lymphatic system is important in the spread of cancerous cells - metastasis.

Blood

While we are considering the circulatory system it is logical to look at blood. Blood is a liquid with suspended cells 30-50% by volume. These cells are of three basic types, erythrocytes or rbcs, leucocytes or wbcs and thrombocytes or platelets. Two of these three cell types are odd, in being anucleate. All originate in the bone marrow, although the number of primary stem cell types is unresolved.

Erythrocytes

By far the commonest blood cells (4-6m/mm3) erythrocytes are classically biconcave enucleate discs 7-8* in diameter. They are red because the cytoplasm is packed with haemoglobin which transports oxygen. They also transport carbon dioxide. Their shape is variable: they are able to deform to squeeze through capillaries. Because they lack a nucleus they have a short lifespan (c 120d) after which their components are recycled (iron) or excreted (bilirubin). Young erythrocytes - reticulocytes (1%) contain a net made up of the remains of the RNA used in haemoglobin synthesis.

Leucocytes

Less common than rbcs (5-10,000/mm3), two main types distinguished according to the presence or absence of cytoplasmic granules.

Granulocytes.

The nuclei of granulocytes are multilobed and cells also called polymorphonuclear leucocytes or polymorphs. The cytoplasm contains two sorts of granules: primary granules - lysosomes - present in all polymorphs and associated with their phagocytic nature secondary or specific granules: which allow identification because they take up specific stains.

We thus distinguish

neutrophils - commonest (50-70%) 10-12* diameter, lobed nucleus, secondary granules unstained. Phagocytic against micro-organisms in blood

eosinophils - (1-4%), 10-12* diameter, lobed nucleus, secondary granules stained pink by eosin. Eat antigen/antibody complexes

basophils - (<1%), 9-10* diameter, lobed nucleus usually hidden by blue staining secondary granules. Not so actively phagocytic -blue granules are heparin and histamine which are released in inflammation and immune responses.

Agranulocytes.

Lack granules, and have a rounded nucleus. Lymphocytes are the commonest (40%), 6-8* diameter, with a large nucleus all but obscuring the cytoplasm . Monocytes (4-8%) larger, 12-16*m diameter with a relatively smaller nucleus.

Platelets

Small (2-3*m) purple staining cell components, non nucleated. They tend to aggregate in clumps. Involved in wound repair and blood clotting. Formed by the disintegration of huge (150*m) megakaryocytes in the bone marrow.

Introductory Anatomy: Respiratory System

The word respiration describes two processes.

Internal or cellular respiration is the process by which glucose or other small molecules are oxidised to produce energy: this requires oxygen and generates carbon dioxide.

External respiration (breathing) involves simply the stage of taking oxygen from the air and returning carbon dioxide to it.

The respiratory tract, where external respiration occurs, starts at the nose and mouth. (Description of respiratory tract from nose to trachea here from overheads) (There is a brief complication where the airstream crosses the path taken by food and drink in the pharynx: air flows on down the trachea where food normally passes down the oesophagus to the stomach.)

The trachea (windpipe) extends from the neck into the thorax, where it divides into right and left main bronchi, which enter the right and left lungs, breaking up as they do so into smaller bronchi and bronchioles and ending in small air sacs or alveoli, where gaseous exchange occurs.

The lungs are divided first into right and left, the left being smaller to accommodate the heart, then into lobes (three on the right, two on the left) supplied by lobar bronchi.

Bronchi, pulmonary arteries and veins (which supply deoxygenated blood and remove oxygenated blood), bronchial arteries and veins (which supply oxygenated blood to the substance of the lung itself) and lymphatics all enter and leave the lung by its root (or hilum). Lymph nodes blackened by soot particles can often be seen here and the substance of the lung itself may be blackened by soot in city dwellers or heavy smokers.

Each lobe of the lung is further divided into a pyramidal bronchopulmonary segments. Bronchopulmonary segments have the apex of the pyramid in the hilum whence they receive a tertiary bronchus, and appropriate blood vessels. The 10 segments of the right lung and eight of the left are virtually self contained units not in communication with other parts of the lung. This is of obvious use in surgery when appropriate knowledge will allow a practically bloodless excision of a diseased segment.

Gaseous exchange relies on simple diffusion. In order to provide sufficient oxygen and to get rid of sufficient carbon dioxide there must be

* a large surface area for gaseous exchange
* a very short diffusion path between alveolar air and blood
* concentration gradients for oxygen and carbon dioxide between alveolar air and blood.

The surface available in an adult is around 140m2 in an adult, around the area of a singles tennis court. The blood in the alveolar capillaries is separated from alveolar air by 0.6* in many places (1* = one thousandth of a mm) . Diffusion gradients are maintained by

* ventilation (breathing) which renews alveolar air, maintaining oxygen concentration near that of atmospheric air and preventing the accumulation of carbon dioxide
* the flow of blood in alveolar capillaries which continually brings blood with low oxygen concentration and high carbon dioxide concentration

Haemoglobin in blood continually removes dissolved oxygen from the blood and binds with it. The presence of this tennis court, separated from the outside air by a very narrow barrier imposes demands on the respiratory tract.
Outside air:

* varies in temperature. At the alveolar surface it must be at body temperature
* varies from very dry to very humid. At the alveolar surface it must be saturated with water vapour
* contains dust and debris. These must not reach the alveolar wall
* contains micro-organisms, which must be filtered out of the inspired air and disposed of before they reach the alveoli, enter the blood and cause possible problems.

It is easy to see that the temperature and humidity of inspired air will increase as it passes down a long series of tubes lined with a moist mucosa at body temperature. The mechanisms for filtering are not so obvious.

Mucus
The respiratory tract, from nasal cavities to the smallest bronchi, is lined by a layer of sticky mucus, secreted by the epithelium assisted by small ducted glands. Particles which hit the side wall of the tract are trapped in this mucus. This is encouraged by: (a) the air stream changing direction, as it

repeatedly does in a continually dividing tube. (b) random (Brownian) movement of small particles suspended in the airstream.

The first of these works particularly well on more massive particles, the second on smaller bits

Cilia

Once the particles have been sidelined by the mucus they have to be removed, as indeed does the mucous. This is carried out by cilia on the epithelial cells which move the mucous continually up or down the tract towards the nose and mouth. (Those in the nose beat downwards, those in the trachea and below upwards).
The mucus and its trapped particles are and bacteria are then swallowed, taking them to the sterilising vat of the stomach.

Length

The length of the respiratory tract helps in both bringing the air to the right temperature and humidity but hinders the actual ventilation, as a long tract has a greater volume of air trapped within it, and demands a large breath to clear out residual air.

Protection

The entry of food and drink into the larynx is prevented by the structure of the larynx and by the complicated act of swallowing. The larynx is protected by three pairs of folds which close off the airway. In man these have a secondary function, they vibrate in the airstream to produce sounds, the basis of speech and singing. Below the larynx the trachea is usually patent i.e. open, and kept so by rings of cartilage in its walls. However it may be necessary to ensure that this condition is maintained by passing a tube (endotracheal intubation) to maintain the airway, especially post operatively if the patient has been given a muscle relaxant.

Another common surgical procedure, tracheotomy, involves a small transverse cut in the neck. If this is done with anatomical knowledge no major structure is disturbed and the opening may be used for a suction tube, a ventilator, or in cases of tracheal obstruction as a permanent airway.

Ventilation and perfusion

The gills of fish and the lungs of birds allow water and air receptively to flow continually over the exchanging surface. In common with all mammals humans ventilate their lungs by breathing in and out. This reciprocal movement of air is less efficient and is achieved by alternately increasing and decreasing the volume of the chest in breathing. The body's requirements for oxygen vary widely with muscular activity. In violent exercise the rate and depth of ventilation increase greatly: this will only work in conjunction with increase in blood flow, controlled mainly by the rich innervation of the lungs.. Gas exchange can be improved by breathing enriched air, which produces significantly reduced times for track events. Inadequate gas exchange is common in many diseases, producing respiratory distress.

Mechanism of breathing

In order to grasp the way in which we breathe we have to grasp the following facts:

Each lung is surrounded by a pleural cavity or sac, except where the plumbing joins it to the rest of the body, rather like a hand in a boxing glove. The glove has an outer and inner surface, separated by a layer of padding. The pleura, similarly, has two surfaces, but the padding is replaced by a thin layer of fluid.

Each lung is enclosed in a cage bounded below by the diaphragm and at the sides by the chest wall and the mediastinum (technical term for the bit around the heart). It is not usually appreciated that the lung extends so high into the neck. A syringe inserted above a clavicle may pierce the lung.

Breathing works by making the cage bigger: the pleural layers slide over each other and the pressure in the lung is decreased, so air is sucked in. Breathing out does the reverse, the cage collapses and air is expelled. The main component acting here is the diaphragm. This is a layer of muscle which is convex above, domed, and squashed in the centre by the heart. When it contracts it flattens and increases the space above it. When it relaxes the abdominal contents push it up again. The proportion of breathing which is diaphragmatic varies from person to person. For instance breathing in children and pregnant women is largely diaphragmatic, and there is said to be more diaphragmatic respiration in women than in men.

The process is helped by the ribs which move up and out also increasing the space available. The complexity of breathing increases as does the need for efficiency. In quiet respiration, say whilst lying on ones back, almost all movement is diaphragmatic and the chest wall is still. This will increase thoracic volume by 500-700ml. The expansion of the lung deforms the flexible walls of the alveoli and bronchi and stretches the elastic fibres in the lung. When the diaphragm relaxes elastic recoil and abdominal musculature reposition the diaphragm again.

Deeper respiration brings in the muscles of the chest wall, so that the ribs move too.

We must therefore understand the skeleton and muscular system of the thoracic wall.

The 12 pairs of ribs pass around the thoracic wall, articulating via synovial joints with the vertebral column - in fact two per rib. The ribs then curve outwards then forwards and downwards and attach to the sternum via the flexible costal cartilages. The first seven pairs of ribs (true ribs) attach directly, the next five hitch a lift on each other and the last two float i.e. are unattached. Costal cartilages are flexible. The first rib is rather different, short, flattened above and below and suspended beneath a set of fairly hefty muscles passing up into the neck, the scalene muscles. Between the ribs run two sets of intercostal muscles, the external intercostals running forward and downwards, the internal intercostals running up and back. These two muscle sheets thus run between ribs with fibres roughly at right angles. When they contract each rib moves closer to its neighbours. Because the lowest ribs float, and the first rib is suspended from the scalene muscles contraction of the intercostal muscles tends to lift rib two towards rib 1, and so on. The ribs are all, therefore pulled up towards the horizontal, increasing anteroom-posterior and lateral thoracic diameters.

These movements are sometimes divided into pump handle movements, the rib abducting on its vertebral joints and bucket handle movements, the rib rotating on its axis around anterior and posterior attachments: these are not necessarily helpful.

With more and more effort put into deeper and deeper breathing the scalene muscles of the neck contract, raising the first rib and hence the rest of the cage, then other neck muscles and even those of the upper limb become involved. A patient with difficulty in breathing often grips a table edge in order to stabilise the limbs so that their muscles can be used to help in moving the thoracic wall.

Problems.

The lungs sometimes fail to maintain an adequate supply of air. The earliest cases of this are seen in infant respiratory distress syndrome. In premature infants (less than about 2 lbs or 37 weeks the cells which make surfactant are not yet active. Surfactant reduces the surface tension in the fluid on the surface of the alveoli, allowing them to expand at the first breath, and remain open thereafter. The sacs either fail to expand, or expand then collapse on expiration and result in laboured breathing. In adults a similar syndrome is due to accidental inhalation of water, smoke, vomit or chemical fumes.

Acute bronchitis is due to infection of the bronchial tree, which may have impaired function due to fluid accumulation. Pneumonia involves the lung proper. Lung cancers a malignancy that may spread to other tissues via the lymphatics in the lung roots.

Introductory Anatomy: Digestive System

Purpose

The digestive system prepares food for use by hundreds of millions of body cells. Food when eaten cannot reach cells (because it cannot pass through the intestinal walls to the bloodstream and, if it could would not be in a useful chemical state. The gut modifies food physically and chemically and disposes of unusable waste. Physical and chemical modification (digestion) depends on exocrine and endocrine secretions and controlled movement of food through the digestive tract.

Mouth

Mouth Food enters the digestive system via the mouth or oral cavity, mucous membrane lined. The lips (labia) protect its outer opening, cheeks form lateral walls, hard palate and soft palate form anterior/posterior roof. Communication with nasal cavity behind soft palate. Floor is muscular tongue. Tongue has bony attachments (styloid process, hyoid bone) attached to floor of mouth by frenulum.
Posterior exit from mouth guarded by a ring of palatine/lingual tonsils. Enlargement = sore throat, tonsillitis.

Food is first processed (bitten off) by teeth, especially the anterior incisors. Suitably sized portions then retained in closed mouth and chewed or masticated (especially by cheek teeth, premolars, molars) aided by saliva Ducted salivary glands open at various points into mouth. This process involves teeth (muscles of mastication move jaws) and tongue (extrinsic and intrinsic muscles). Mechanical breakdown, plus some chemical (ptyalin, enzyme in saliva). Taste buds allow appreciation, also sample potential hazards (chemicals, toxins)

Swallowing

In leaving the mouth a bolus of food must cross the respiratory tract (trachea is anterior to oesophagus) by a complicated mechanism known as swallowing or deglutination which empties the mouth and ensures that food does not enter the windpipe.

Swallowing involves co-ordinated activity of tongue, soft palate pharynx and oesophagus. The first (buccal) phase is voluntary, food being forced into the pharynx by the tongue. After this the process is reflex. The tongue blocks the mouth, soft palate closes off the nose and the larynx rises so that the epiglottis closes off the trachea. Food thus moves into the pharynx and onwards by peristalsis aided by gravity. If we try to talk whilst swallowing food may enter the respiratory passages and a cough reflex expels the bolus.

Oesophagus

The oesophagus (about 10") is the first part of the digestive tract proper and shares its distinctive structure. Basic tissue layers of the gut are

1. mucosa. Innermost, moist lining membrane. Epithelium (friction resistant stratified squamous in oesophagus, simple beyond) plus a little connective tissue and smooth muscle.
2. submucosa. Soft connective tissue layer, blood vessels, nerves, lymphatics
3. muscularis externa. Typically circular inner layer, longitudinal outer layer of smooth muscle
4. serosal fluid producing single layer.

Stomach

C shaped, left side abdominal cavity (because liver is on right). Cardioesophageal sphincter guarding entrance from oesophagus is of doubtful anatomical integrity (though functionally the diaphragmatic pinch cock serves). Pyloric sphincter guarding the outlet is much better defined. Fundus, body and pylorus recognised as distinct regions. Stomach secretes both acid and mucus (for self protection). Surface area increased by rugae. Serves as a temporary store for food which is also churned by muscular layers (three here) to form chyme, creamy substance voided via pyloric sphincter to duodenum

Duodenum

First part of small intestine. C shaped 10" long and curves around head of pancreas and entry of common bile duct (accessory organs of digestion, pancreas, liver see below). Chemical degradation of small controlled amounts of food controlled by pyloric sphincter begins here, enzymes secreted by pancreas and duodenum itself aided by emulsifying bile (which also lowers pH). Duodenal ulcers caused by squirting of acid stomach contents into duodenal wall opposite sphincter.

Small Intestine

Jejunum (8 feet) and ileum (12 feet) continue degenerative process. Surface area increased by plica circulares (circular folds) carrying villi: cells of villi carry microvilli. Each villus has a capillary and a lacteal (lymphatic capillary) Absorption of digested foodstuffs is via these to the rich venous and capillary drainage of the gut. Towards the end of the small intestine accumulations of lymphoid tissue (Peyer's patches) more common. Undigested residue of food is rich in bacteria.

Large Intestine

Jejunum terminates at caecum. Caecum is small saclike evagination, important in some animals as a repository for bacteria/other organisms able to digest cellulose. A blind ending appendix may give trouble (appendicitis) if infected. The large intestine has three longitudinal muscle bands (taenia coli) with bulges in the wall (haustra) between them. These may evaginate in the elderly to become diverticuli and infected in diverticulitis.

The large intestine resorbs water then eliminates drier residues as faeces. Regions recognised are the ascending colon, from appendix in right groin up to a flexure at the liver, transverse colon, liver to spleen, descending colon, spleen to left groin, then sigmoid (S-shaped) colon back to midline and anus. Anus has voluntary and involuntary sphincter and ability to distinguish whether contents are gas or solid. No villi in large intestine, but many goblet cells secreting lubricative mucus.

Accessory digestive organs

Salivary glands

Three pairs, parotid, submandibular, sublingual. Mumps begins as infective parotitis in the parotid glands in the cheek. The others open into the floor of the mouth. Saliva is a mixture of mucus and serous fluids, each produced to various extents in various glands. Also contains salivary amylase, (starts to break down starch) lysozyme (antibacterial) and IgA antibodies. In some mammals (and snakes!) saliva may be poisonous, quietening down living prey.

Pancreas

Endocrine and exocrine gland. Exocrine part produces many enzymes which enter the duodenum via the pancreatic duct. Endocrine part produces insulin, blood sugar regulator.

Liver and gallbladder

Bile, a watery greenish fluid is produced by the liver and secreted via the hepatic duct and cystic duct to the gall bladder for storage, and thence on demand via the common bile duct to an opening near the pancreatic duct in the duodenum. It contains bile salts, bile pigments (mainly bilerubin, essentially the non-iron part of haemoglobin) cholesterol and phospholipids. Bile salts and phospholipds emulsify fats, the rest are just being excreted. Gallstones are usually cholesterol based, may block the hepatic or common bile ducts causing pain, jaundice.

Liver

Multifunctional: important in this context since the capillaries of the small intestine drain fat and other nutrient rich lymph into it via the hepatic portal system.

Introductory Anatomy: Excretory & Reproductive Systems

During the process of evolution we quite often find that structures evolved to do one thing are no longer relevant. The appendix is a good example: useful in animals feeding on grass it has no function in man, has become small and may ultimately disappear. In other cases these relict organs may be taken over for quite another purpose. This is the case with the excretory and reproductive systems which are anatomically and evolutionary linked, and where parts of the excretory system have been taken over by the reproductive system.

To understand this we must go back to our coelomate ancestor.

Remember this had a gut and a coelom lined with thin mesothelium. Now a large cavity with a thin wall like this is ideal for dumping waste, and it seems that the coelom was so used. The result, of course is that it would gradually fill with ions, salts, water and what have you. This seems to have been countered by forming paired lateral ducts, lined with cilia and called nephrotomes.

The cilia control the direction of the fluid, outwards. Interestingly these excretory ducts probably also carried gametes to the sea, even at this early stage.

Now the animals we are talking about were segmented, like sliced bread, and had one coelom and one pair of nephrotomes per segment. When segmentation was abandoned in favour of an open plan coelom the nephroptomes became rationalised with paired openings (still) but only one exit to the sea, towards the rear. The open plan coelom developed at about the same time as the circulatory system, and this became involved. The dorsal aorta ran close to the nephrotome and formed a knot of capillaries, a glomerulus, associated with each nephrotome. Finally the ciliated duct to the coelom was lost

This set-up, a glomerulus, a nephric tubule (essentially a space) and a duct passing posteriorly has formed the basis of the kidneys ever since. I say kidneys not because we have two of them but because during vertebrate history there have been three pairs of kidneys. The most primitive of these was anterior, the next more posterior and the last most posterior. They are called pronephros, mesonephros and metanephros.

The pronephros is still seen in some fish and amphibian larvae: it has glomeruli, ciliated segmented ducts opening into the coelom and a pronephric duct running posteriorly to the cloaca.

The mesonephros is the kidney of most fish , some adult amphibia and many mammalian embryos: it has glomeruli, no ciliated ducts and uses the pronephric duct (which is now called the mesonephric duct).

The metanephros develops behind the mesonephros to form the definitive kidney in mammals. The important fact here is that it develops its own duct, the metanephric duct or ureter, which develops from the cloaca and runs forward to the developing third generation kidney.

The reproductive system and its ducts.
The gonads develop in the same dorsolateral region as the kidneys. Gonads are initially equipped with two sets of ducts. Why? Well remember that nephrotomes, ciliated ducts passing to the outside originally carried germ cells. When the connection to the coelom was lost an alternative duct system, the parmesonephric ducts were developed to provide passage for the germ cells. When, in turn the mesonephric duct became redundant it was reclaimed by the reproductive system. As it happens the male reproductive duct develops from the mesonephric duct and the female from the paramesonephric.

Reproductive system
The whole embryology of the reproductive system is fascinating. The sex of an embryo is determined at conception by its chromosome content. In man 46+XX is female, 46 +XY is male. However the gonads, when they first form are of an indifferent type, that is the same in both sexes. Another point of interest is that the actual germ cells, which are to become eggs and sperm develop in another part of the embryo entirely from the gonads - in fact near the heart. They then migrate through the tissue of the embryo to the gonad. By the time they arrive the gonad has prepared itself by becoming male or female. In the male changes are under the influence of the Y chromosome (we know this because of the few unfortunates who don't have one , or who have an unusual number of X chromosomes). Part of the male development is the formation of interstitial cells, the hormone producing (testosterone) cells of the testis. The testosterone influences duct development. With testosterone the mesonephric duct develops to become the vas deferens and associated structures; without it the mesonephric duct atrophies and the paramesonephric duct becomes the oviduct and most of the uterus. In some individuals the tissues are unable to respond to testosterone. Lets look at the developing male and female reproductive systems. In the male the indifferent gonad responds to the effects of the Y chromosome to develop testis cords which become horseshoe shaped and enclosed within the thickened tunica albugina of the gonad. The free ends of the horseshoes are in contact with the redundant mesonephric duct. The paramesonephric duct develops in response to placental and maternal hormones, but is unused and later regresses. A little later we find that the mesonephric duct has continued

to develop and forms the epididymis, the ductus (vas) deferens and the seminal vesicles. The paramesonephric duct has regressed, to be represented only by the appendix testis proximally and the utriculus prostaticus, a small diverticulum in the prostate gland distally.
You will also note that the right hand side of the slide shows a different relationship between parts, because it covers the period of the descent of the testes. These were originally situated on the posterolateral abdominal wall but, as they develop migrate (by differential growth) to lie behind an outpushing of the anterior abdominal wall, the vaginal process (vagina here as elsewhere means scabbard). This is assisted by the gubernaculum (the governor) a band of contractile connective tissue. The testes ultimately lie in the scrotum, and the duct system is rearranged to pass from the scrotum back into the abdominal wall, in the inguinal canal, before it unites with the terminal duct of the excretory system, the urethra to enter the penis.

In the female things take a slightly different course. The medullary cords (the testicular cords of the male) degenerate because there is no Y chromosome. They are replaced by epithelial inpushings of the covering of the developing ovary, which break up to form follicles.

This is where the white mouse comes in. This is a black-eyed white mouse, not the normal albino which has pink eyes. It is white, anaemic and sterile because it carries a mutation in a gene which governs the ability of migrating cells to navigate. One of these great navigations is that of pigment cells into the coat, the other is germ cells to the ovary and testis. The germ cells in these mice set off from the region ahead of the developing heart and migrate to the gonads - but never get there, so the mice are sterile. Usually the germ cells arrive in the testis or ovary and populate the cords or follicles. The paramesonephric ducts in the female persist and go on to make the Fallopian tubes or oviducts the uterus and the upper part of the vagina. The lower part of the vagina is ectodermal and shares its derivation with the male. Just as the testis and ovary were indeterminate at first, so are the external genitalia At four weeks we find a genital tubercle marking the anterior end of a common cloaca, serving both urinary and genital systems. By six weeks an anal region has budded off posteriorly. In the female the tissue on each side of the cloaca becomes the major and minor labia, and vagina and urethra open between them. The genital tubercle becomes the relatively small clitoris. In the male the labia unite in the midline to form the scrotum and part of the penis, the head of which is formed by the genital tubercle. If this seam remains incomplete hypospadias results.